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Investigations in Special "High Radon Areas" in Germany

G. Keller[1], M. Schütz[1], A. J. Khan[1]

Abstract

*The main source of high radon concentration indoors is the exhalation of radon from the soil. In the western part of Germany, two interesting regions, "Eifel" and "Hunsrück", are selected for these radon investigations. The first region is an area with silt and sandstone of low uranium content but with tectonic fractures caused by postvolcanic activity, whereas in the part of the "Hunsrück" under consideration, the uranium concentration in the ground formerly allowed the extraction of uranium ores. An electrostatic deposit of the first radon daughter (Polonium-218-ion) onto a surface barrier detector and the subsequent analysis of the measured alpha spectra enables the determination of the concentration of radon in dwellings, its diffusion through and its exhalation rate from the soil. A maximum indoor concentration of radon of 8 kBq*m^{-3} in a bedroom and approximately 35 kBq*m^{-3} in a cellar room were determined in a house built in 1976. The daily variation between the minimum and the maximum concentration indoors amounts to a factor of ten. In these regions the radon concentration outdoors varies between 20 and 150 Bq*m^{-3}. The exhalation rates of radon from the soil are found to range from 0.002 to 1 Bq*m^{-2}*s^{-1}. The effects of sealing the ground slab with polyurethane and removing the air under the ground slab by suction will be presented.*

KEY WORDS:
Radon, Dwellings, Radon exhalation, Radium, Radon mitigation.

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[1] Institut für Biophysik, Universität des Saarlandes, D-6650 Homburg/Saar, Federal Republic of Germany

Introduction

The radon entry rate from the soil underneath the buildings is the decisive source for high concentrations of radon in the indoor atmosphere. The average radon contribution of building materials to indoor concentrations determined to be about 30 Bq*m^{-3} (Stranden, 1989; Keller and Folkerts, 1984) may be neglected in "high radon areas". The determination of the indoor radon concentration in any house in the country being practically impossible, criteria have to be found to identify "high radon areas" easily. The purpose of the study is to investigate the reasons for high indoor radon values in several areas in Germany. In these regions, sealing methods for reducing radon entry into houses and subsoil suction should be recommended before the construction of new buildings. At this early planning stage, measures against radon entry are more effective and cheaper than for existing houses. The results of radon measurements in two geologically different territories, "Döttingen/Eifel" and "Ellweiler/Hunsrück", will be discussed.

Experimental Methods

The village Döttingen is located in the "Rhenish Schiefergebirge" in an area with silt and sandstone of low uranium content having less than 2 ppm. Here passive track etch time-integrating radon dosimeters had been distributed to 17 dwellings during three winter months in 1988. Three radon dosimeters were exposed in each of the examined houses, one in a cellar, one in a bedroom and a third one in a living room respectively. The dosimeter contains a polycarbonate detector foil at the bottom of the plastic diffusion chamber. It is enclosed by a hydrophobic fibre glass filter and consequently only radon gas and not its daughter products diffuses into the sensitive volume. The emitted alpha particles cause tracks in the foil during the exposure time. After electrochemical etching, the radon con-

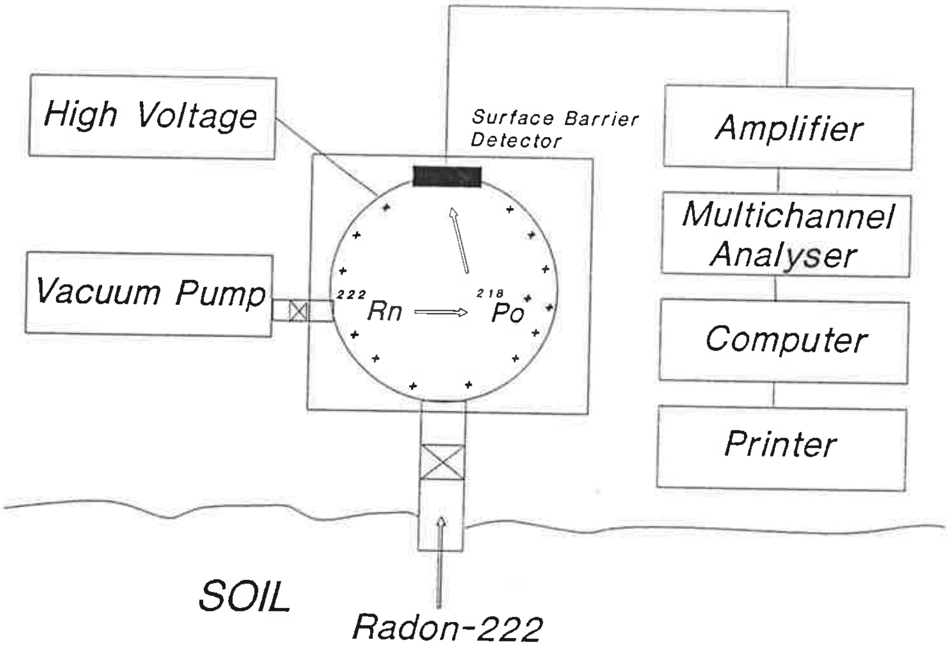

Fig. 1 Measuring arrangement for the determination of radon potential of the soil

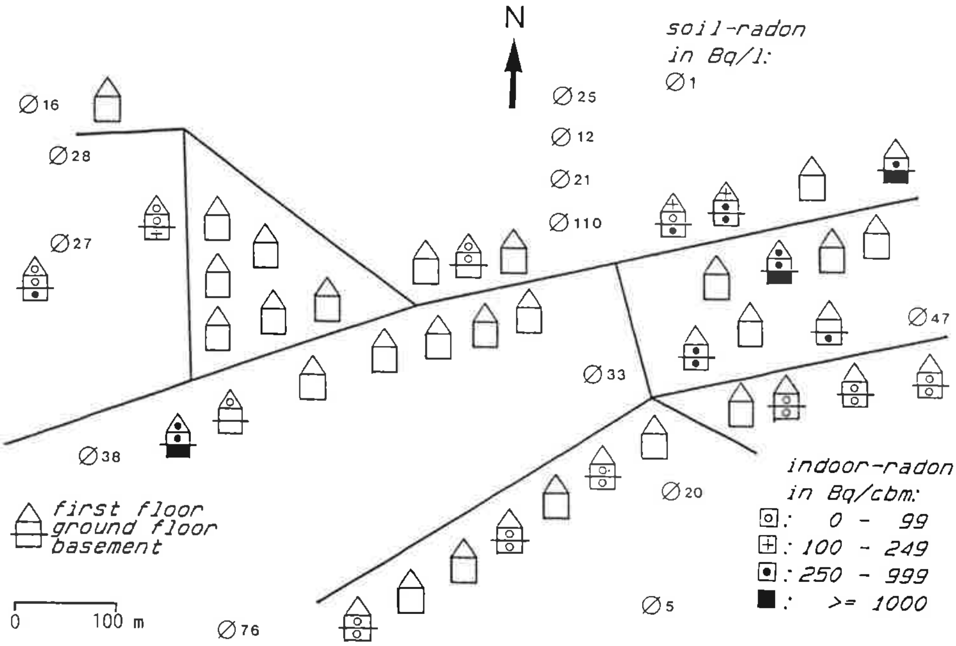

Fig. 2 Radon-222 concentration indoors in Bq*m^{-3} and soil radon in Bq/l in Döttingen/Eifel

centration is calculated from the track density. Complete evaluation of the data was performed by the Kernforschungszentrum Karlsruhe.

The village Ellweiler is located at the border of the Hunsrück in an area with deposits of feldspar and porphyry with high uranium content of the soil. A former uranium pit is located only 200 m north of the village. Uranium ores with a maximum content of 0.2% had been mined from this pit until 1975. In Ellweiler, charcoal radon dosimeters were exposed in 40 houses during three days in February 1989. Taking into consideration a correlation factor for humidity, the mean radon concentration indoors during the exposure time is determined by gamma spectroscopy with a High Purity Germanium Detector some days after the end of the exposure. Indoor radon concentrations were also determined by active-field measurements. The measuring devices collect the air into a metallic sphere and deposit the positively charged Polonium-218 ions onto a negatively charged surface barrier detector. The radon concentration is determined by subsequent spectroscopy of

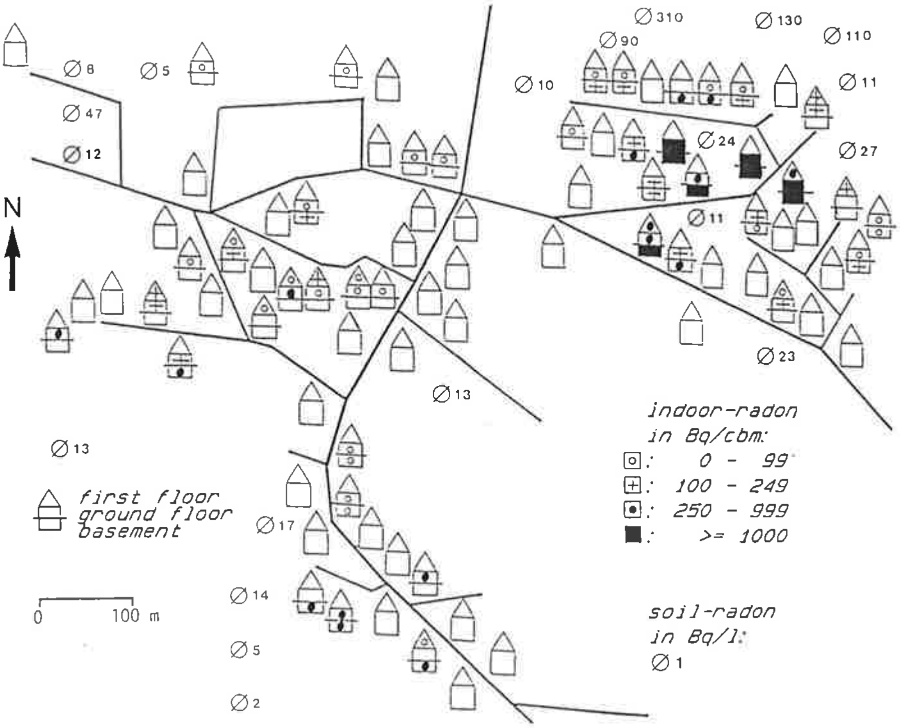

Fig. 3 Radon-222 concentration indoors in Bq*m^{-3} and soil radon in Bq/l in Ellweiler/Hunsrück

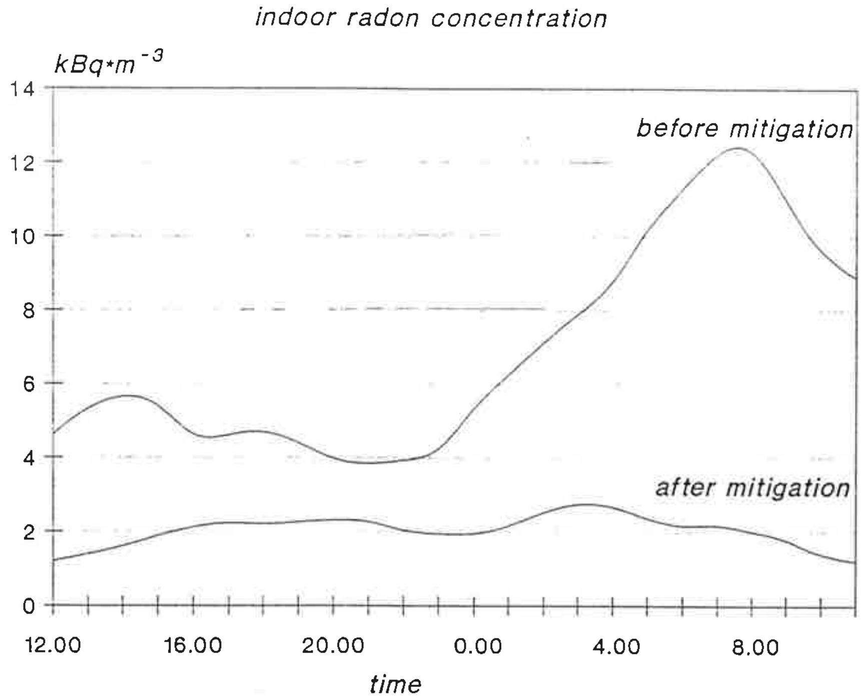

Fig. 4 Continuous measurements of radon concentrations in a cellar before and after mitigation

the emitted alpha particles. A modified arrangement with smaller spheres was used to determine the radon concentration in the soil air (see Figure 1.). By means of a similar method, the radon exhalation rate from the soil may be calculated as follows: the radon gas exhales from the soil, passes through an insulated intermediate area and reaches the measuring chamber consisting of a metallic hemisphere with a metallic grid at its bottom. The exhalation rate of radon is now determined from the increase of radon concentration inside that hemisphere during several successive measuring cycles (Keller and Schtüz, 1988). The concentrations of the short-lived radon daughters are determined by air sampling on

Table 1 Long-term measurements of outdoor radon in the east (A) and south (B) of Ellweiler (average +/- 1 std.dev.)

Time period	^{222}Rn-concentration Bq/m^3 A	B
May '89 – Sep '89	60 +/- 12	39 +/- 16
Sep '89 – Feb '90	48 +/- 14	40 +/- 15
Feb '90 – May '90	160 +/- 10	33 +/- 16

a membrane filter and immediate alphaspectroscopy (Keller et al., 1982).

Results

The results of the measurements of indoor radon concentration in Döttingen and additionally some typical values of the radon concentration in the subsoil are shown in Figure 2. In nearly half of all the houses in Döttingen that were built during the last 20 years, radon values less then 100 Bq*m^{-3} have been found. The older houses are situated along the main street and show higher radon concentrations. About one quarter of all houses are very old buildings in which radon concentrations of more than 1 kBq*m^{-3} were measured during the three-month period of the cold season. Around Döttingen, radon concentrations in the subsoil air up to a depth of 2 m were investigated in the following spring. Maximum values of more then 110 kBq*m^{-3} along the main street and a background level of about 5 kBq*m^{-3} confirm that Döttingen is an "abnormal radon area". High radon concentrations in the soil and high indoor radon values coincide in an area which is known for its postvolcanic fractures and faults. Apparently these structures allow fast diffusive and convective transport of radon through the soil. Consequently the measurements of radon exhalation rates at the surface of the soil yielded their highest values of more than 20 mBq*m^{-2}*s^{-1} in that faulted zone, whereas the background level of 2 mBq*m^{-2}*s^{-1} proved the typical value of a "low radon area".

For political reasons the investigations in Ellweiler required fast information about the radon risk to the residents. Therefore the planned measurements with track etch detectors had to be replaced by charcoal dosimeters which give earlier results. The results of our measurements are shown in Figure 3. With low radon concentrations of less than 100 Bq*m^{-3} in 20% of all dwellings, values between 100 and 250 Bq*m^{-3} in 50%, values above 250 up to 1000 Bq*m^{-3} in 20% and over 1000 Bq*m^{-3} in the remaining 10% of all the dwellings, Ellweiler is established as a "high radon area". Additionally, some long-term outdoor measurements could be performed around Ellweiler during spring (see Table 1). The radon concentration in the subsoil varies between 2 and 300 kBq*m^{-3}, the maximum values being found on the hill around the old uranium pit, the lower ones in the valley in the centre of the village. The

Table 2 Seasonal variation of outdoor and indoor Radon-222-concentration (average +/- 1std.dev.)

Meteorological parameters	Outdoor ^{222}Rn-conc. (Bq/m^3)	Indoor ^{222}Rn-conc. (Bq/m^3)	Equilibrium equivalent ^{222}Rn-conc. (Bq/m^3)	Indoor equilibrium factor
Spring-like temp: 22 °C rel. hum.: 55% at.pres.: 990 hPa hot, partially cloudy	20.5 +/-6.0	59.7 +/-38.0	7.3 +/-7.2	0.12 +/-0.06
Summerly temp: 25 °C rel. hum.: 37% at.pres.: 985 hPa sunny, calm	13.4 +/-4.0	31.0 +/-10.0	11.5 +/-7.3	0.34 +/-0.10
Autumnal temp: 11 °C rel. hum.: 90% at.pres.: 985 hPa rainy	14.6 +/-5.4	89.0 +/-45.0	17.8 +/-11.0	0.19 +/-0.07
Wintry temp: 0 °C rel. hum.: 70% at.pres.: 1000 hPa dry, sunny	19.8 +/-7.0	167.0 +/-219.0	51.7 +/-89.0	0.25 +/-0.10

Table 3 Radium-226-concentration in drinking, ground and surface water samples near Ellweiler (average +/- 1 std.dev., (maximum and minimum))

	Winter	Summer
Drinking water (mBq/l)	73.3 +/- 31.0 (13-132)	86.0 +/-68.0 (32-280)
Number of samples	11	11
Surface water (mBq/l)	75.5 +/-51.0 (20-216)	141.9 +/-93.0 (16-312)
Number of samples	24	24
Ground water (mBq/l)	400	450
Number of samples	1	1

radon exhalation rate of the soil around the former pit and along its southern slope down to the village, where possibly uranium ore lodes exist, reaches up to 100 $mBq*m^{-2}*s^{-1}$. To get a better estimation of the average of indoor and outdoor radon concentration over the period of a whole year, additional measurements in any of the four seasons were carried out during the following year. The results are presented in Table 2. They indicate a seasonal variation of indoor radon by a factor of five, with maximum values during the cold season and minimum values during the summer. From the simultaneously measured equilibrium equivalent radon concentration, a mean indoor equilibrium factor of 0.23 can be calculated. Some additional results of measurements of Radium-226-concentrations in water samples from the region of Ellweiler are shown in Table 3.

Radon Mitigation Methods

High concentrations (35 $kBq*m^{-3}$ in a cellar room, 8 $kBq*m^{-3}$ in a bedroom and 4 $kBq*m^{-3}$ in a living room) were determined in a 10-year-old house. The radon gas from the soil entered the house via a small cellar room deep in the ground. In this cellar the former massive concrete plate had been removed and after excavation a new plate had been installed on a 0.7 m lower level without connection to the walls or the foundations. Up to 2 cm wide fissures and cracks allowed radon to enter easily from the ground into the house. In this cellar room mitigation methods such as plastic sealing and subsoil ventilation were tested. The fissures between wall, foundation and floor slab were first widened and then filled with polyurethane (PU) resins. The floor was then covered with a 4 mm thick PU layer and the cellar walls with a PU layer of 1 mm thickness. For vertical sealing of the walls a special method of high pressure packing with PU was used. The radon concentrations in the unventilated cellar decreased by a factor of about ten after these mitigation measures. An additional ventilation system was installed to suck off the subsoil air. This measure reduced the radon activity once more by a factor of about five. After all these mitigation measures the radon concentrations in this house amounted to values of only a few per cent of the former concentration.

Conclusions

The inhalation of short-lived Radon-222 daughters represents the largest contribution to the natural radiation exposure of the human population. Based on the ICRP 1987 dose conversion factor, a mean breathing rate of 12.5 l/min for indoors and an average equilibrium factor of 0.4, a Radon-222 concentration indoors of 2 $kBq*m^{-3}$ yields an annual effective dose of about 50 mSv. Several epidemiological studies on uranium miners (Sevc et al., 1976) and other underground miners show that the lung cancer risk may increase at these radiation doses. With a view to radiation protection for the human population, the identification of "high radon areas" is of fundamental importance.

The radon concentration of the soil is the decisive factor in such "high radon areas". The results of these investigations highlight that in general two parameters are responsible for the magnitude of the radon concentration of the soil, firstly a high uranium-radium content of the ground and secondly fast transport of radon through the soil (Swedjemark, 1987).

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